Appendix K: Hydrology

This section documents information on the hydrology of the Quinault River above Lake Quinault specifically related to study questions. A more detailed description of overall hydrology of Quinault watershed and determination of flood frequency numbers used in this appendix can be found in the Watershed Analysis, Chapter 2 (QIN, 1999). Because this study evaluates river channel changes over the last century, it is important to determine when the majority of floods that can result in river channel changes occur. The question has also been raised as to whether flood magnitudes have been impacted by natural and human induced changes in the river valley over the last century. Given the possibility that in-channel restoration projects may be implemented as part of future studies, it is also important to know the probability and magnitude of flood flows. Because it is expected that Lake Quinault dampens the flood peak during storms, the flows measured at the gage at the lake outlet are likely smaller than those experienced in the Upper Quinault. A cursory hydrologic analysis was performed to predict the equivalent river flows for standard flood frequency intervals in the Upper Quinault watershed, using several methods for comparison. Discharge values presented in this section are provided in English units because of the familiarity and provision of data in this format from U.S. Geological Survey (USGS).

Discharge and Precipitation Measurements

The Quinault River drains from the glaciated Olympic Mountains in northwest Washington State, with a total drainage area above the outlet of Lake Quinault of 684 km^2 (264 mi^2), and 606 km^2 (234 mi^2) above the inlet of Lake Quinault. About 18 km upstream from the inlet to Lake Quinault, two stems of the Quinault River join together informally referred to as the Forks. Above the Forks, the North Fork Quinault has a drainage area of 208 km^2 (80.3 mi^2), and the East Fork has a drainage area of 234 km^2 (90.3 mi^2). River flows have been measured at the outlet of Lake Quinault from October 1, 1911 to the present time by the USGS (Gage 12039500) with the exception of water years 1923 to 1925 where no data is available. Discharge data was also recorded at a location on the North Fork Quinault (above the Forks Bridge) from November 1, 1964 to September 30, 1986 (USGS Gage 12039300, drainage area on North Fork of 74.1 square miles). The average annual flow is 2,876 ft^3/s (81.4 m^3/s). Precipitation was measured at the Quinault Ranger Station from 1961 to 1990, and shows average monthly precipitation varied between 3 to 24 inches during this time period (QIN, 1999). The average annual precipitation is 146 inches. A representation of how precipitation varies throughout the watershed is shown in Figure 3 of Attachment 1 of this appendix.

Flow patterns

The majority of floods occur in the Upper Quinault between November to February as a result of winter storm events (Figure 1). Flows gradually decline until late April, and then increase again to mid-June due to melting of winter snowpack (QIN, 1999). Low flow periods during drier summer and fall months are sustained from Anderson Glacier and numerous snowfields in the upper watershed (QIN, 1999).

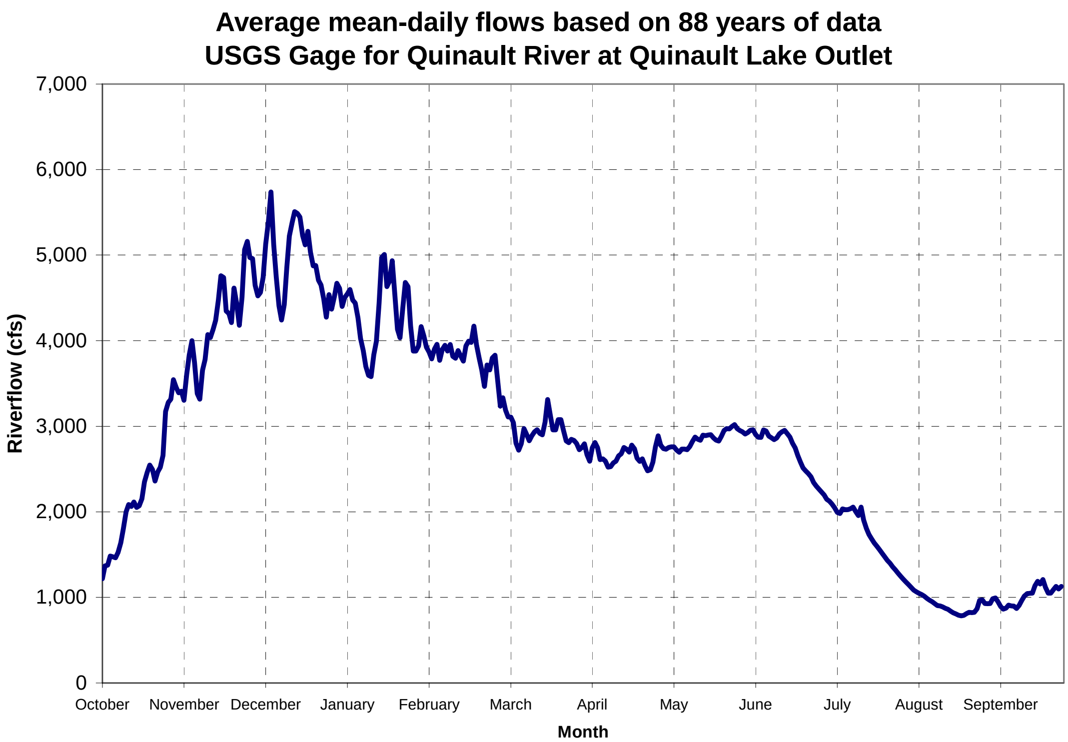

Figure 1. Average mean daily flows for a typical water year based on historical gaging station data at USGS Gage 12039500 (Data downloaded from USGS Web Site).

Flood Events

Major known floods occurred in 1909, 1949, 1955, 1961, and 1997 (Figure 2). The 1909 flood was estimated by USGS after the gage was installed in 1911. The discharge was inferred from observed high-water marks and the relation between stream gage height and discharge that was established after operation of the streamflow station near the outlet of Lake Quinault (QIN, 1999). The flood of November 1949 reportedly brought an 18-foot rise in the level of Lake Quinault, and completely inundated the Falls Creek Campground on Lake Quinault (Aberdeen Daily World, 1949 as reported in QIN, 1999). The 1949 flood was between a 10- and 25-year flood (instantaneous peak 42,300 ft^3/s). Local landowners have observed that high lake levels do not necessarily occur at the same time the river is at its highest flood stages, although occasionally the two do coincide to create a "worst case" flooding scenario such as in 1949. Table 1 and Figure 2 shows the amount and relative frequency of floods occurring between aerial photographs and maps evaluated which is important to consider when evaluating rates and magnitudes of channel change. Almost all time periods had at least one flood greater than the 5-year flood except for 1962 to 1973, and 1998 to 2001.

Table 1. Number and relative frequency of floods between aerial photographs and maps.

Time Period (years)	Number Years Spanned	Return Period Range				
		50- to 100-Year Flood	25- to 50-Year Flood	10- to 25-Year Flood	5- to 10-Year Flood	2- to 5-Year Flood
1909 to 1929	20	1			4	5
1929 to 1939	10				2	3
1939 to 1952	13			1	1	3
1952 to 1958	6		1		1	2
1958 to 1962	4			1		5
1962 to 1973	11					3
1973 to 1982	9			1	5	4
1982 to 1994	12			2	3	7
1994 to 1998	4		1		2	5
1998 to 2001	3					2
2001 to 2002	1			1		1

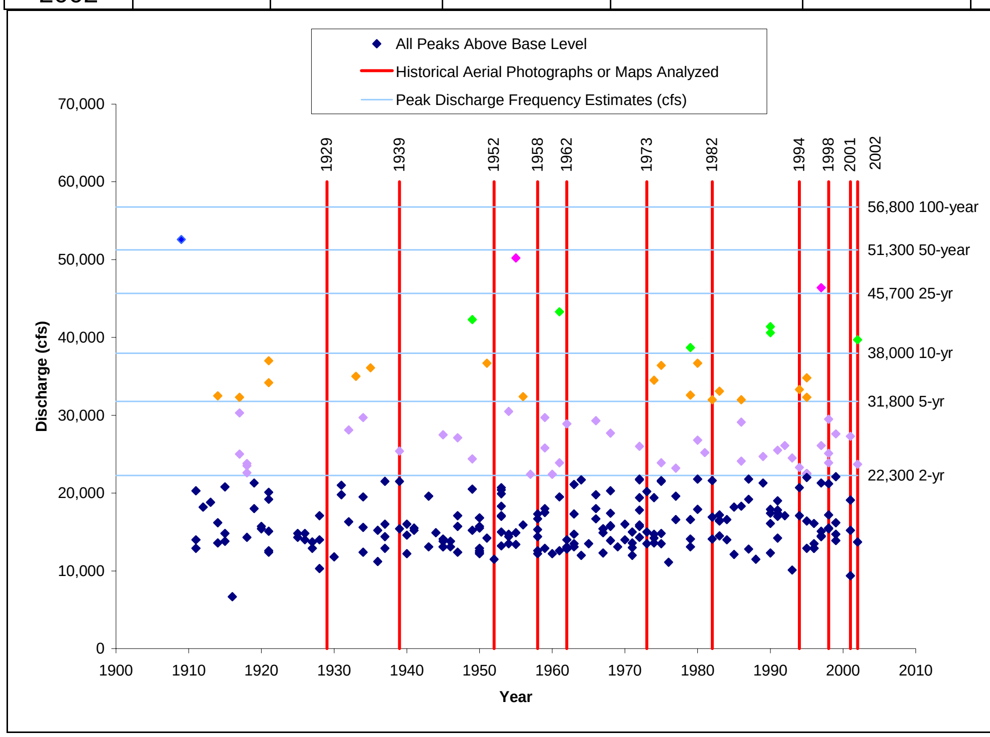

Figure 2. Instantaneous peak discharges above base level measured at USGS gaging station at outlet of Lake Quinault are shown. Peaks are color coded to show how they relate to flood frequency estimates labeled on right vertical axis. Date of historical aerial photographs and maps acquired are shown in red lines for reference.

Hydrologic Trends

Analysis of sockeye by the Quinault Department of Fisheries indicates that numbers started to substantially decline between 1950s (see Figures 2 and 3 in main report), yet the majority of disturbance to the watershed occurred in the early part of the twentieth century. Therefore, it is of interest to evaluate the hydrologic trends over the last 100 years. The majority of sediment transport and significant channel shifting typically occurs during the 2-year and greater floods. One school of thought is that over a long period of time the majority of channel changes occur during the 2-year floods because it is the flood that occurs the most frequently. However, larger floods can result in more extensive channel changes because they inundate more areas of the floodplain. If floods are occurred at a greater frequency or magnitude during certain parts of the last century, it could help explain the timing of channel response to human disturbance.

The Watershed Analysis (QIN, 1999) noted that a relatively dry climate period ended in the late 1940's in the Pacific Northwest, and was followed by a relatively wet period that ended in 1977. From 1977 to 1998, another dry period was occurring (QIN, 1999). However, it is noted in the Watershed Analysis that these are multi-year trends based on long-term precipitation records. A particular year within the dry or wet designated periods could actually be fairly wetter or drier than overall trend during that time period.

The Watershed Analysis (QIN, 1999) evaluated historical gage data between 1911 and 1998 to look for any changes in hydrology that could have occurred as a result of natural or man-made changes that have taken place in the basin upstream of the USGS gage at the outlet of Lake Quinault. The study evaluated mean monthly flows, low flows, and peak discharges. No visually detectable trends were observed in low or peak flows (QIN, 1999). Some additional analysis of peak flows by Reclamation does indicate a trend of common floods occurring more frequently in the latter part of the twentieth century.

The Quinault Department of Fisheries showed a sockeye decline starting in the 1950s (see Figure 2 and 3 in main report). The USGS gaging station data at the outlet of Lake Quinault was evaluated to determine if there was any evidence of floods occurring at a more frequent or higher magnitude since the 1950s that may have had an impact on sockeye habitat. The peak flow data shown in Figure 2 indicates the first and largest documented flood occurred in 1909, probably when human disturbance in the river channel area was still fairly localized. The second two largest flood peaks that occurred in 1955 and 1997 are of similar order of magnitude and do not indicate that the largest flood peaks have changed over the last century.

The USGS gaging station record is available for annual peak flows and for all peak flows above 15,000 ft^3/s. Both sets of gaging station data were broken out into time periods between 1911 to 1950 and 1951 to 2002. For all flows above 15,000 ft^3/s, the occurrence of more common floods (2-, 5-, and 10-yr) floods were compared between the two time periods (Table 2). The USGS gage record is only available for 35 water years in the first set of data and 51 years in the second set so it is difficult to directly compare the number of floods between each time period. However, when averaged out per year the frequency of floods greater than the 2- and 5-year floods appear to be occurring about twice as often between 1951 to 2002 than in 1911 to 1951 (Table 2). Therefore, from 1911 to 1950 the 2-year flood occurred about once every two years, and between 1951 and 2002 occurs almost annually. There was only 1 flood greater than a 10-year flood between 1911 and 1950, yet there were 7 floods greater than the 10-year flood between 1951 and 2002.

Table 2. Occurrence of common floods between 1911 and 1951 and 1952 and 2002.

Flood Frequency	Total Number of Floods Greater than Flood Frequency Value		Flood Occurrence Per Year for Floods Greater than Flood Frequency Value	
	1911 to 1950	1951 to 2002	1911 to 1950	1951 to 2002
2-yr flood	18	49	0.51	0.96
5-yr flood	7	19	0.20	0.37
10-yr flood	1	7	0.03	0.14

Another way to compare the two time periods is to compute the 2-year flood for each time period using a Log Pearson III computation. Data for the USGS gaging station between 1911 and 2004 was utilized (one additional year than other computations). Using this method, the 2-year flood between 1911 and 1950 was 19,989 ft^3/s and between 1951 and 2004 was 24,504 ft^3/s, indicating it has increased about 23%.

Mean monthly flow analysis (QIN, 1999) did indicate that certain periods of time since 1911 have been higher or lower than the average (Figure 3). The Watershed Analysis (QIN, 1999) concluded that the trends in monthly flows were closely tied to fluctuations in precipitation: “With few exceptions, the cumulative departures for precipitation agree closely with those for streamflow. This close agreement indicates that most of the variation in streamflow trends is probably a result of precipitation trends, with little or no influence from any natural or man-made changes that may have taken place in the basin.” The Watershed Analysis did recognize that forest harvesting and road construction in the watershed may have an effect of increasing annual water yield, decreasing low flows, and increasing magnitude of high flows but it was noted that additional analysis would be needed to determine the magnitude of impact on the Quinault River.

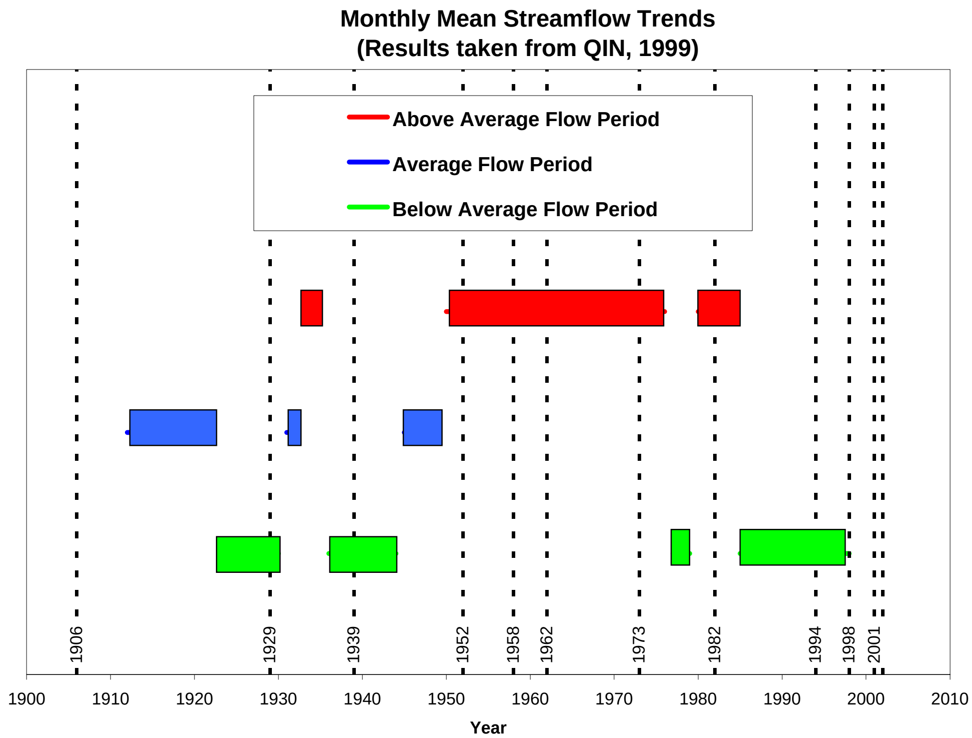

Figure 3. Periods of monthly mean streamflow that were average, above average, or below average based on monthly streamflow data from USGS gaging station at Lake Quinault (12039500). Results taken from Watershed Analysis (QIN, 1999).

Change in Flood Peak Magnitude throughout Study Reach

The largest sub-basins between the Forks and Lake Quinault that contribute water and sediment to the Quinault River are Big Creek and Finley Creek (see Figure 2, Attachment 1). Many other small sub-basins drain onto terrace surfaces in the study reach. Attachment 1 provides estimates for the ungaged portion of the upper Quinault watershed to compare the relative difference in flood peaks in the downstream direction as drainage area increases. A USGS approach incorporating drainage basin area and average precipitation estimates were used to develop the flood frequency estimates for the ungaged basin (methodology described in Attachment 1). Additional flood frequency estimates were needed for input data to computing the change in total stream power (discharge times slope) within the study reach (Attachment 2). Sub-basins were chosen for total stream power calculations based on major tributary inputs to the study reach: at Forks which is just below confluence of the North and East branches of Quinault River at RK 18 (sub-basin 1), just below the confluence with Big Creek at RK 8 (sub-basin 2), at the inlet to Lake Quinault (sub-basin 3). The USGS approach indicates the 2- to 100-year floods at the Forks are increased by roughly 20% by RK 8 (Big Creek confluence), and by a total of 30% at RK 0 at the lake inlet.

Dampening Effect of Lake Quinault

Lake Quinault is a natural unregulated reservoir with a surface area of approximately 15.1 km^2 (3,729 acres). A 1995 survey documented a maximum depth of 73 m (240 ft) (Gubala, 1995). The lake dampens both peak and low flows between the inlet and the outlet where the gaging station is located (QIN, 1999). Two methods of analysis document this potential dampening effect: 1) comparing normalized discharges for a series of floods on the Queets and Quinault Rivers which showed 31 to 38% decrease (QIN, 1999); and 2) computing a reverse reservoir routing and comparing average inflow to average outflow of the lake which showed a 5 to 26% decrease for mean daily values and about a 41% decrease for hourly values (peaks above 15,000 ft^3/s).

To determine the potential dampening effect of the lake during flood flows, the Watershed Analysis (QIN, 1999) normalized discharges to drainage area size for the Quinault River gage at the lake, a gage on the nearby Queets River, and a gage on the Humptulips River near Humptulips. The top five normalized peak flow events between 1933 to 1960 at each site were then averaged and compared. In that analysis it was shown that the average normalized peak flow value for the Quinault River below Lake Quinault was about 31 to 38 percent below the average normalized values for the two other sites. It is interesting to note that the drainage area of the Quinault River (264 square miles) and the Elwha River at the McDonald Bridge gage (269 square miles) are roughly equivalent, but the 2-year flood on the Quinault at the lake outlet (22,300 ft^3/s) is 1.7 times that of the nearby Elwha River (13,300 ft^3/s). Although both rivers drain from the same mountain range in Olympic National Park, the Elwha drains north into the Strait of Juan de Fuca and may likely result in different storm events controlling winter floods.

Reservoir routing is a commonly used approach to look at the impacts of the lake's storage capacity on incoming discharge versus releases from the reservoir. However, reverse reservoir routing (going from outgoing to incoming flow) is much more complex. Reverse reservoir routing can be used to compare average inflows to average outflows for purposes of this discussion. A reverse reservoir routing model was developed in a spreadsheet to evaluate the potential dampening effect of the lake by looking at the change in storage. The gage at the lake outlet has a relationship between river stage and lake elevation that was used to determine the change in lake storage (QIN, 1999). Changes in storage volume were based on change in lake elevation as incoming discharge varies. Daily stage values were available from USGS for the gaging station at the lake outlet from 1998 to 2002. Hourly stage was downloaded from the USGS web site for the October 2003 flood, which had two peaks between a 5- and 10-year flood frequency. Mean-daily discharges greater than 15,000 ft^3/s were attenuated 5 to 26% by Quinault Lake. Hourly discharge values for two peaks above 15,000 ft^3/s during the October 2003 flood greater than 15,000 ft^3/s were attenuated 41 and 42% by Quinault Lake (Figure 4). This indicates that values recorded at the USGS gage at the outlet of Lake Quinault may be about 30 to 40% lower than the river flow in the upstream river near the inlet to Lake Quinault. Flows would reduce in magnitude in the upstream direction from the inlet to the Forks as the drainage basin area reduces.

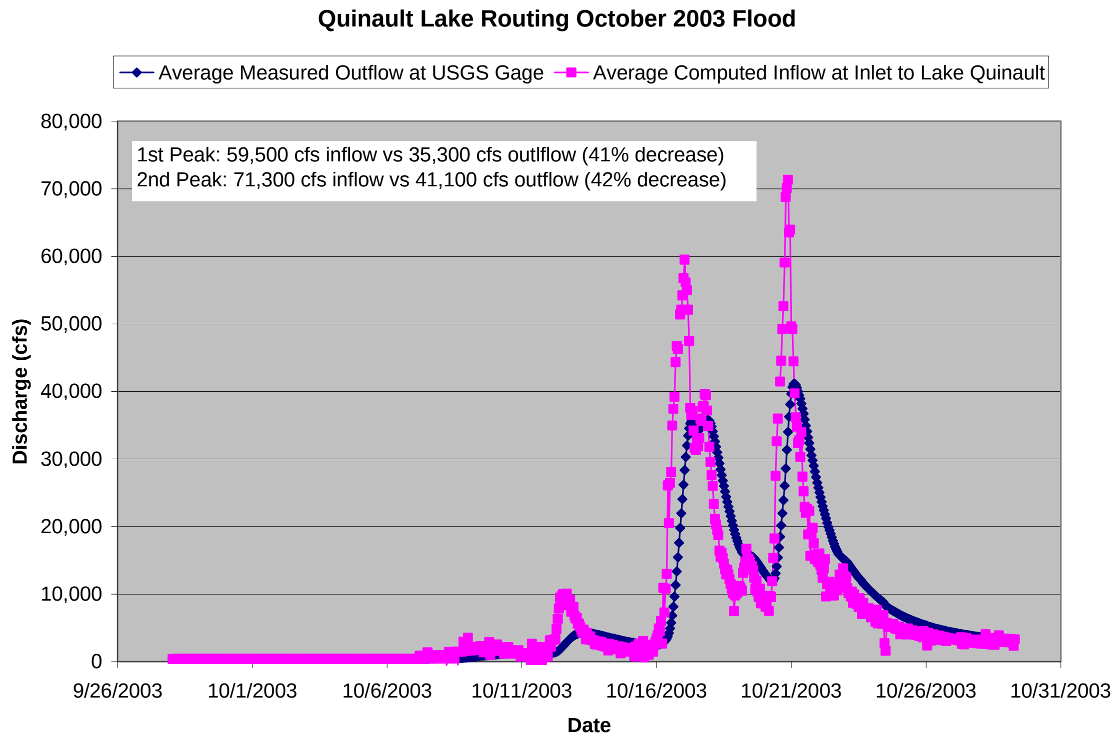

Figure 4. Reverse reservoir routing results for October 2003 flood.

Recommendations for Monitoring Future Hydrologic Change

The Watershed Analysis (QIN, 1999) suggested the following studies to improve the understanding of hydrology in the Upper Quinault River:

- Maintaining and expanding existing network of streamflow stations within the watershed.
- Establishing at least one paired-basin investigation of effects of forest practices on streamflow.
- Improving and expanding collection and archiving of meteorological data.
- Assessing and, if necessary, revising the preliminary map of current wetlands, and monitoring impacts on wetlands from timber harvesting, road construction, and recreation.

Additional suggestions from landowners during our study presentation were to develop a hydrologic model of the watershed and develop a better flood prediction and monitoring tool.

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Attachment 1: Peak Flow Frequency Estimation

Prepared by Ken Bullard

Authorization: The River and Sedimentation Group requested assistance with ongoing Quinault River studies. Available stream gage information below Lake Quinault shows the effect of regulation and is not suitable for determining peak flows at various stream locations above Lake Quinault. This study uses the regional regression equations prepared by the USGS for peak flow frequency estimation and does not rely on the stream gage record for the Quinault River below Lake Quinault.

Regional Peak Flow Regression Analysis: The USGS prepared a report in 1997 that provided a means to calculate peak flows for ungaged, unregulated stream locations throughout Washington State (Sumioka, S. S. and others, 1998). This report relied on available unregulated peak flow stream gage data from several hundred sites. The entire state of Washington was further divided into nine regions representing similar hydrologic and meteorologic conditions.

Using recommended Bulletin 17B (Interagency Advisory committee on Water Data, 1982) calculation techniques for peak flow frequency analysis at each of these sites, the peak flows for several return periods were calculated. The calculated peak flows for the various return periods were used as the dependent variable in a multiple regression analysis. The independent variables were various measured hydrologic and meteorologic variables such as drainage area, basin slopes, vegetation measurements, and mean annual precipitation amounts averaged over the basin. The results of the multiple regression analysis, within each of the previously established regions, indicated which of the independent variables played the most important roles in predicting the calculated peak flows for each return period. For each region the most important of the tested independent variables were used to establish regression equations that could then be used to calculate the peak flow for a specified return period.

The Quinault River lies in what was defined as region 1 by the USGS for Washington State. This region includes all of the Pacific Ocean drainages in Western Washington State, and specifically the Pacific Ocean drainages of the Olympic Peninsula. Figure 1 displays a general location map for the Upper Quinault River basin. Sixty-one independent unregulated peak flow stream gages were used in the regression analysis for USGS region 1. For this region the most significant variables in the regression analysis were the drainage area and the mean annual precipitation amount calculated for the basin.

The drainage areas used were the entire contributing, non-regulated drainage area established by the USGS for each of the 61 gage stations. Mean annual precipitation amounts for the USGS study were taken from maps prepared by the National Weather Service in 1965 (U. S. Weather Bureau, 1965). The mean annual precipitation amount was averaged over the entire drainage basin. The Weather Service mean annual precipitation map from 1965 is no longer readily available, but more recent mean annual precipitation maps, in GIS form and based on data from 1951 to 1990, are available from the NRCS (Natural Resources Conservation Service, 1998) and can be used for this study.

The standard error of the estimated peak flows for this region was between 32 and 37 percent for return periods between 2- and 100-years. The ability of a regression equation to reliably estimate the peak streamflow having selected recurrence intervals at ungaged sites is measured by the error of prediction. The error of prediction is the measure of confidence in the estimated peak streamflow and describes the range within which an estimate would occur two-thirds of the time. The range of drainage areas applicable for using the regression equations is between 0.15 and 1,294 square miles, and for mean annual precipitation amounts ranging from 45 to 201 inches. The actual regression equations developed by the USGS are given in the published report (Sumioka, S. S. and others, 1998) and are not repeated here.

Peak Flood Flow Analysis for the Quinault River Basin: To apply the published USGS regression equations to the Quinault River basin measures of the drainage area at various locations in the basin and the associated basin average mean annual precipitation with in the drainage area were derived. Figure 2 displays the basin and sub area boundary map used in this study.

The drainage basins for six locations above Quinault Lake were determined by use of available 7 ½ minute DEMs (digital elevation models) and the WMS (Watershed Management Program, version 7.0) (Brigham Young University, 2003). For each of these locations a drainage basin boundary was established and the contributing area measured. In addition a shape file was created with an appropriate projection that could be used with the mean annual precipitation maps.

The mean annual precipitation amounts for each of the six locations in the Quinault River basin were determined by overlaying the basin areas defined by shape files created in the basin area calculation process onto the available NRCS mean annual precipitation maps, (NRCS, 2001). The mean annual precipitation maps display contours with ranges of values representing the mean annual precipitation. The average value in each precipitation band was determined, and the amount of area of each elevation band contained in each sub area above the desired flow point on the Quinault River was calculated in ArcView. A weighted area average value of the MAP (mean annual precipitation) for the total area above each flow point was then calculated. This MAP was used in the regression equations to determine the desired peak flows for each return period at each flow point. In the original USGS regression equation determination, MAP values were determined from a now outdated map. The use of the more recent MAP values may provide some minor inconsistency in the theoretical application of the regression equations. This difference in the source of the MAP values is assumed to be minor. Figure 3 displays the six sub areas along with the MAP contours used in this study.

Table 1 presents a summary of the results of the peak flow calculations by the method described above. The location of the flow points would be at the most downstream end of the sub area given in the table. Table 2 provides the basic drainage area and MAP data used with the USGS equations to produce the peak flow values in Table 1.

Table 1
Upper Quinault River, Washington
Summary of Peak Flow Computations
(Values computed by USGS Regression Equations (Sumioka, S. S. and others 1998))
(ft^3/s)

Flow Point at the Downstream End of Sub Area

Return Period (years)	Sub Areas 7	6	5	4	3	2
2	25,250	20,740	10,150	10,620	7,960	9,610
10	39,570	32,520	15,930	16,710	12,480	15,130
25	46,500	38,220	18,720	19,640	14,670	17,780
50	52,490	43,140	21,140	22,170	16,560	20,070
100	59,040	48,510	23,750	24,910	18,600	22,550

Table 2
Upper Quinault River, Washington
Data for USGS Regional Peak Flow Regression Equations

Flow Point at the Downstream End of Sub Area

Sub Area Flow Point	Total Area (sq. mi.)	Mean Annual Precipitation (inches)	Major Drainage Basin Included
7	233.2	143.1	Upper Quinault R, Big Crk, Raley Crk
6	184.9	145.1	Upper Quinault R blw Howe Crk
5	90.3	139.0	S F Quinault R, Howe Crk
4	80.3	157.3	N F Quinault R
3	71.6	135.7	S F Quinault R, Graves & O'Neil Crk
2	69.2	162.2	N F Quinault R, Rustler Crk, Kimta Crk

Comparison with other results: An analysis of the peak flow data for the USGS Gage below Lake Quinault (USGS Gage 12039500) was performed. The peak flows were analyzed using a standard log-Pearson III analysis and the results are summarized in table 3. The results were in general were a few percent below the results given in table 1 above for the various return periods at flow point 7. Reasons for this difference include a difference in drainage area, the fact that the Lake Quinault provides some attenuation effect on peak flows, rain falling on the lake appears in the single station statistics but not the regional analysis, and the differences that are expected to occur between a regional analysis and a single station peak flow analysis. Given these differences in data sources and calculation techniques the results computed specifically for the Upper Quinault River are actually quite close.

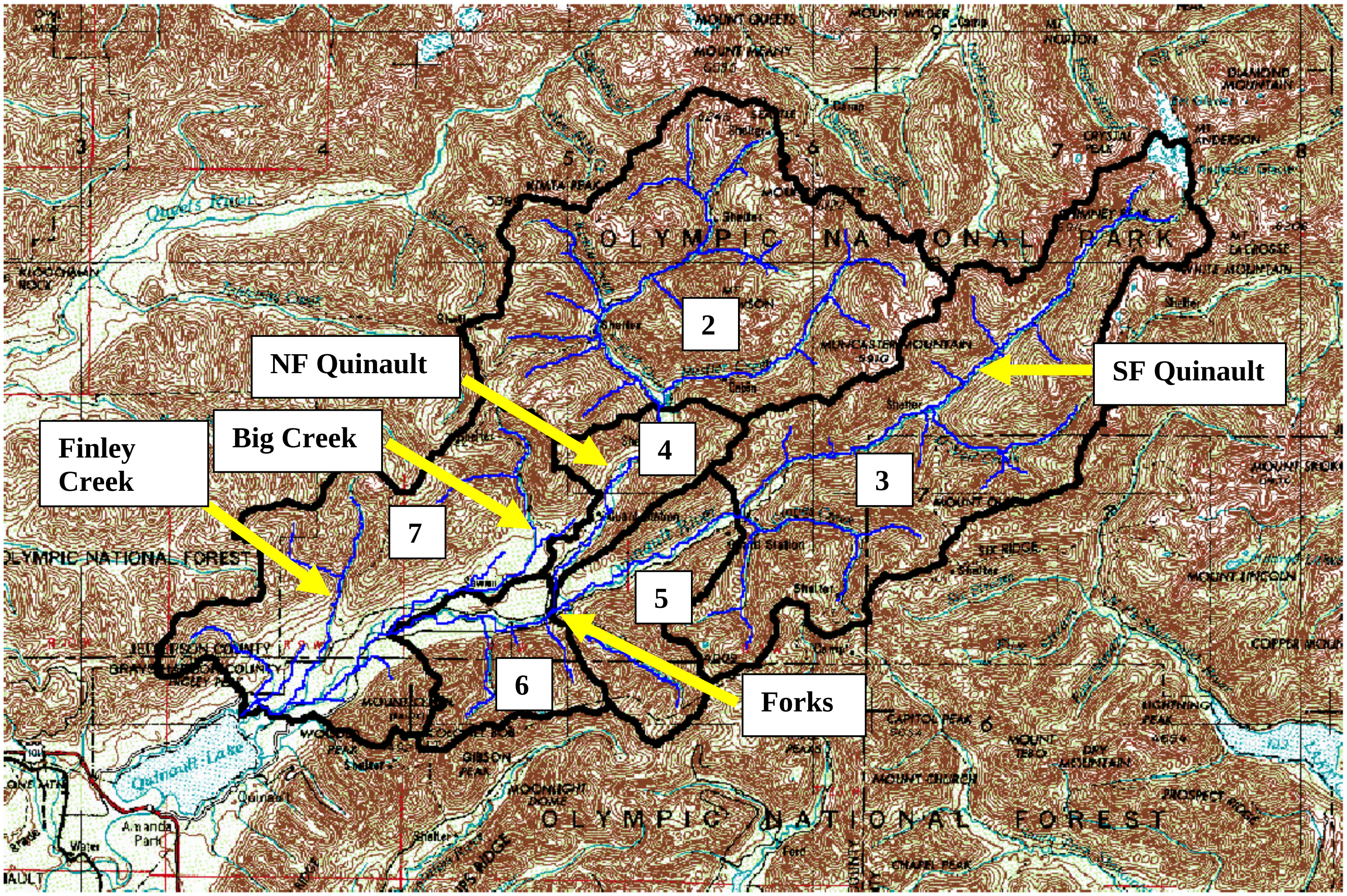
Table 3
Upper Quinault River, Washington
Summary of Peak Flow Computations
(Values computed by USGS Regression Equations (Sumioka, S. S. and others 1998) and log-Pearson III analysis of USGS Gage 12039500)

Return Period	USGS Regional Regression (Flow Point 7)	Single Gage (12039500) LPIII Analysis	Differences	
(years)	(ft^3/s)	(ft^3/s)	(ft^3/s)	(percent)
2	25,250	22,262	2,988	11.8
10	39,570	37,977	1,593	4.0
25	46,500	45,657	843	1.8
50	52,490	51,263	1,227	2.3
100	59,040	56,772	2,268	3.8

In the Quinault River Watershed Analysis (1999) an analysis of selected peak flows, for a common period of record, for two nearby gage sites was provided. The top five events at the two different gage sites were analyzed by normalizing the peak flow data and representing the selected peaks as a unit discharges (ft^3/s/sq. mi.). The top five normalized peak flow events at each site were then averaged. In that analysis it was shown that the average normalized peak flow value for the Quinault River below Lake Quinault was about 31 to 38 percent below the average normalized values for the two other sites. The Watershed Analysis study did not document the return periods on any of the peak flows studied.

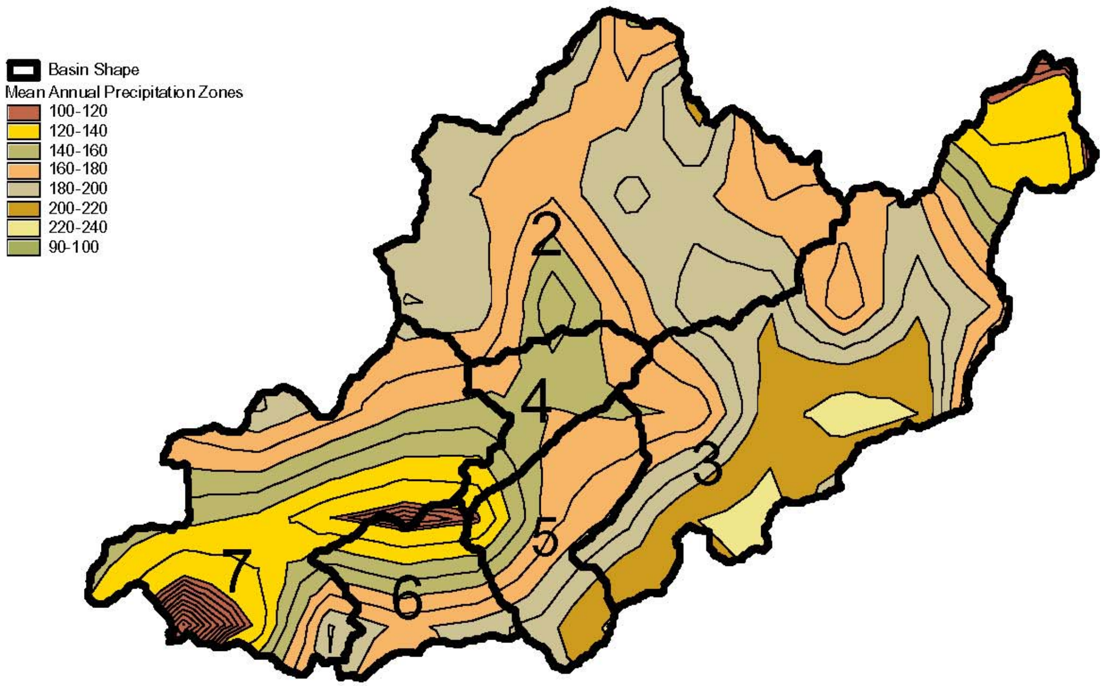
Upper Quinault River Basin Drainage Basin Location

Figure 1



Quinault River Basin above Quinault Lake, WA
Basin and sub area delineations

Figure 2



Quinault River Basin
Above Quinault Lake
Mean Annual Precipitation Contours

Figure 3

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Attachment 2: Additional Locations of Peak Flow Frequency Estimates

Additional estimates of peak flood frequency were needed at different locations than described in Attachment 1. These new locations were needed for input data to computing the change in total stream power (discharge times slope) within the study reach. Sub-basins were chosen for total stream power calculations based on major tributary inputs to the study reach: just below Forks of the North and East branches of Quinault River at RK 18 (sub-basin 1), just below the confluence with Big Creek at RK 8 (sub-basin 2), at the inlet to Lake Quinault (sub-basin 3). The absolute values computed by the method described in Attachment 1 have a certain level of unknown error that cannot be resolved without measured gage data to compare to. However, the method is based on known gaging station data and the relative differences between sub-basin outlet locations 2, 3, and 4 provide a reasonable comparison of change in flood frequency magnitude between the upstream end of the study reach at the Forks, and the downstream end at the inlet to Lake Quinault.

The USGS approach based on drainage basin size and precipitation indicates the discharge at the Forks is increased by roughly 20% by RK 8 (Big Creek confluence), and by a total of 30% at RK 0 at the lake inlet.

Table 1. Quinault River Basin - Total Drainage Areas and MAP for USGS Regression Equation Input

Location Description	WMS Sub basin Number Flow point location	Sub basin Area (square miles)	Total Area above flow point (square miles)	Mean Annual; Precipitation for total area (inches)
RK 18 at Forks	1	170.8	170.8	141.0
RK 8 at Big Creek	2	33.1	203.9	143.0
RK 0 at inlet to lake	3	29.5	233.4	140.0

Table 2. USGS regression equation constants.

Return Period (years)	Equation Constant	Area Exponent	Precipitation Exponent
2	0.350	0.923	1.24
10	0.502	0.921	1.26
25	0.590	0.921	1.26
50	0.666	0.921	1.26
100	0.745	0.922	1.26

Table 3. Quinault River estimated flood peaks using USGS equations. Flow point located at downstream-most point of each sub-basin as shown in Figure 1.

Return Period (years)	Location 1 (RK 18) (peak ft^3/s)	Location 2 (RK 8) (peak ft^3/s)	Location 3 (RK 0) (peak ft^3/s)
2	18,610	22,300	24,600
10	29,170	34,950	38,530
25	34,280	41,070	45,280
50	38,700	46,360	51,120
100	43,510	52,140	57,490

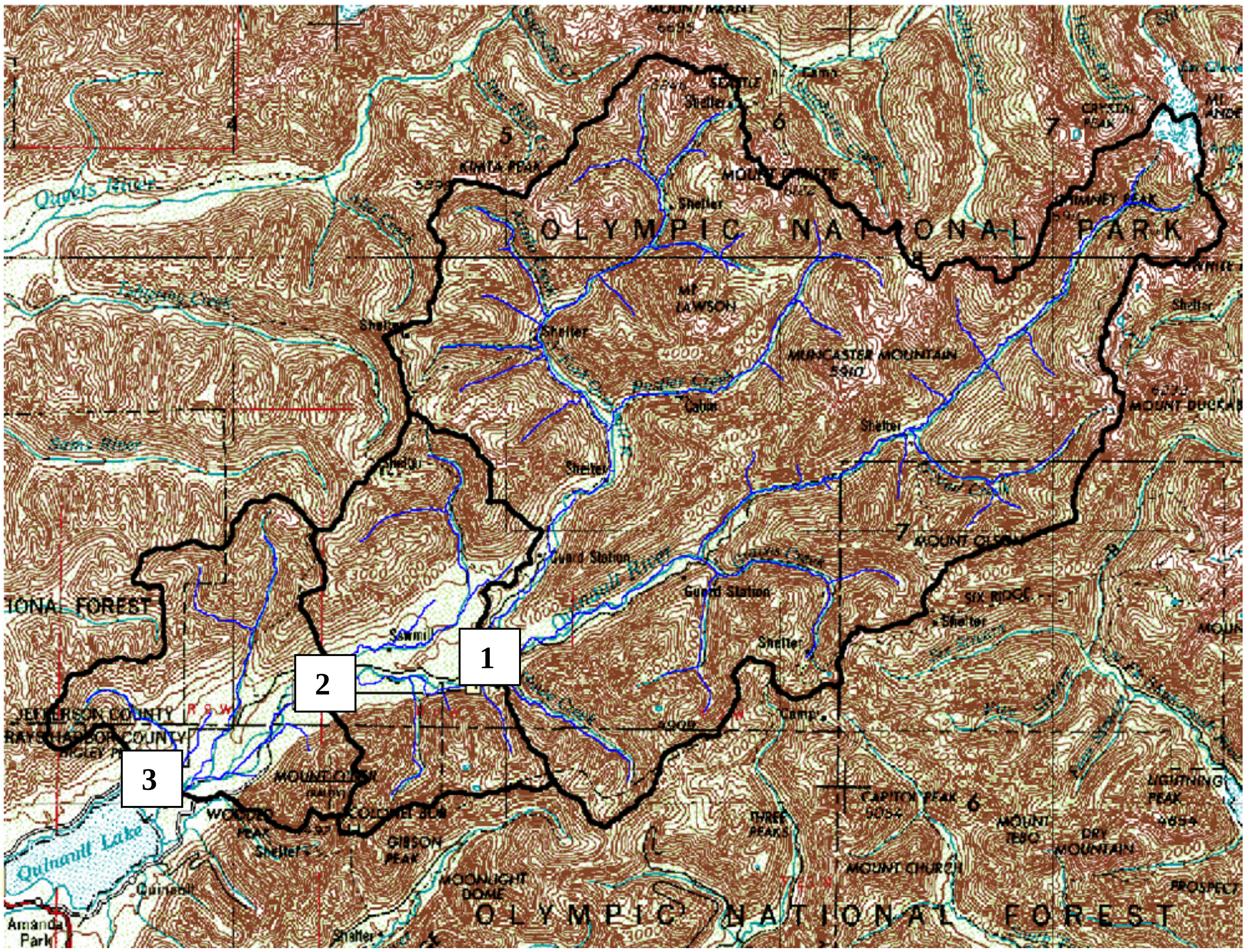

Figure 5. Location and extent of sub-basins delineated in study reach.